§23. Transport Analysis of Impurity LHD Peripheral Regions during Neon Gas-puff

Kawamura, G., Kobayashi, M., Dai, S., Mukai, K.,
Sano, R., Peterson, B., Shoji, M.,
Feng, Y. (Max-Planck IPP, Greifswald Germany)

In order to control heat load on divertor plates, methods of power reduction such as advanced divertor concepts, impurity seeding, detachment are proposed and actively studied. Impurity gas puff is one of possible methods and has been investigated experimentally in LHD[1]. We have developed transport model of plasma, impurity and neutral particles in the peripheral plasma by using EMC3-EIRENE[2),3)] and applied to LHD[4),5)]. The code solves fluid equation with Monte-Carlo technique and has the capability of resolving perpendicular transport across a magnetic field line in 3D space. We modeled a 1/20 toroidal block of the LHD plasma and the plasma mesh system of EMC3 covers the peripheral plasma which has long connection length, roughly >10m. The core region is excluded from the simulation and modeled as boundary conditions at the last closed flux surface (LCFS). The magnetic axis is located at R_{ax}=3.6m and the vacuum field, i.e., zero beta plasma, is employed to make the calculation mesh.

We analyzed a LHD discharge with neon gas puff by EMC3-EIRENE. Input parameters were based on the discharge #117478 (17th cycle, 2013) and determined to reproduce a radial distribution of the plasma: input power P_{in}=11.6MW, electron density at core-SOL boundary $n_e=3.3\times10^{19}$/m3, perpendicular transport coefficients $D=D_{imp}=1.0$ m^2/s and $\chi_e=\chi_i=0.4$ m^2/s. After a neon puff, the plasma becomes steady state and the enhanced radiation continued until the end of the discharge. That fact indicates that some amount of neon gas was confined in the device and recycled through ionization and surface recombination in steady state. Therefore, we modeled the neon as no gas puff but surface source on the divertor plates and no wall loss to realize 100% recycling. The amount of neon is determined to have the same amount of total radiation as that measured by bolometer, 2.5MW. We simulate carbon and neon, which have 0.24MW and 1.4MW radiation, respectively, and the remaining 0.86 MW radiation is from hydrogen.

We compared distribution of density and radiation of carbon and neon and found that much neon accumulate in the ergodic region than carbon, see Fig. 1(a). The physical reason of it can be understood from neutral transport and force acting on ions. Neon has higher ionization energy and deeper penetration into the plasma. The penetration limit is drawn in Fig 1(a) as white lines. Carbon has high density outside the limit, e.g. left side of the white line, and neon has mainly inside the limit. This limit is consistent with the distribution of electron temperature. Figure 1(b) shows distribution of force balance on impurity ions. Positive value (red) means friction force dominant and negative value (blue) means thermal force dominant. Friction force pushes ions toward downstream and thermal force is opposite. Neon has deeper penetration and can access to the thermal force dominant region and therefore neon is transported toward upstream more easily than carbon. That is the reason of larger accumulation in the ergodic region.

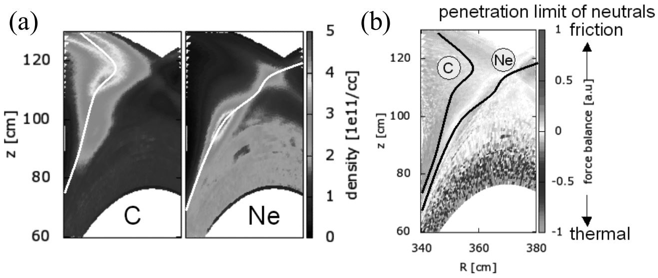

Fig. 1: distributions of (a) C and Ne density and (b) force balance on impurity ions. The white and black lines in the both figures represent penetration limit of neutral impurity particles.

Helical plasma has complicated structures of magnetic field lines and impurity transport is also complicated in space. Figure 2 shows density distribution of neon ions along a magnetic field line. The field tracing was carried out from the neon density peak in Fig. 1(a) toward the both directions, e.g. positive and negative. Thermal force is dominant in field line except near the divertor plates, where fast plasma flow exists because of collisional presheath. The neon ionized in the divertor plasma experiences successive ionization to higher states and transported toward the upstream. In the middle of the field line, flow speed of impurity becomes zero and causes a large peak. Ions flow from the both side and escape from the field line due to perpendicular transport.

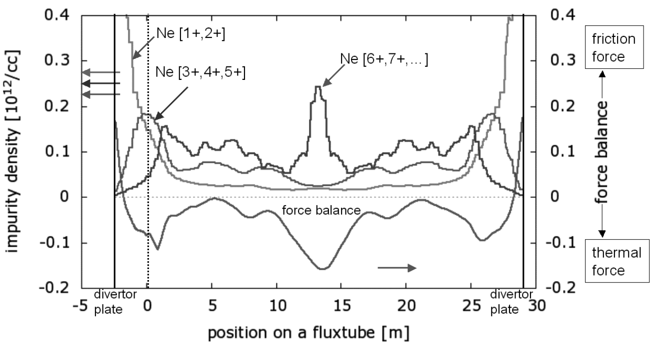

Fig. 2: distributions of neon density with three charge- state groups (green, blue and magenta lines) and force balance (red line) along a magnetic field line.

1) K. Mukai et al., Nucl. Fusion **55** (2015) 083016
2) Y. Feng et al., Contrib. Plasma Phys. **44** (2004) 57.
3) D. Reiter et al., Nucl. Fusion **47** (2005) 172.
4) G. Kawamura, et al., Contrib. Plasma Phys. **54** (2014) 437.
5) M. Kobayashi et al., Nucl. Fusion **53** (2013) 033011